Climate Change and Causation

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*49 CLIMATE CHANGE AND CAUSATION: JOINING LAW AND CLIMATE SCIENCE ON THE BASIS OF FORMAL LOGIC

I. Introduction

A strict application of legal tests to find *the cause* of an event, combined with a traditional emphasis on finding the *necessary cause* in a counterfactual inquiry and a judicial demand of certainty, sets a high threshold for making causal statements. Often, this threshold of the "but for" test has been found to be over-exclusionary.[1] In the context of climate change, the emerging field of probabilistic event attribution provides significant information to explain past events and to forecast future events related to anthropogenic climate change.[2] This field of climate science focuses on making robust statements about the role of climate change, quantifying changes in the likelihood of extreme weather events and attributing these to greenhouse gas ("GHG") emissions or even certain emitters. For example, one ***50** study looking at the Argentina 2013-2014 heatwave found that this event was made five times more likely due to total anthropogenic emissions and attributed thirty seven percent of that probabilistic increase to GHG emissions of the European Union.[3]

Given that climate scientists are now able to make robust statements quantifying the likelihood of extreme weather events in changing climate conditions, does this allow us to make causal inferences, ultimately ascertaining responsibility in law? We argue that the traditional "but for" or "conditio sine qua non" inquiries used to establish causal relations are inadequate to develop legally meaningful causal explanations in the climate change context. However, a coherent approach to causal analysis is possible within a matrix we introduce. While not attempting to offer a full philosophically rooted, universal model of a theory on causality,[4] we expose some criteria that the law uses to test causation in the hope to subject these to a much needed discussion of climate change and causation which will affect international law, domestic law, and climate science. Our matrix is based on the observation that in different categories of cases outside climate change, courts occasionally soften the legal concept of causation to recognize fairness considerations when differentiating mere co-relation from cause and effect. These normative judgments govern the measure of damages recoverable in tort law and in contract law.[5]

***51** However, this article does not focus on the normative dimension of legal causation, where the outcome of cases is adjusted if the mechanistic application of the "but for" test yields unfair results. These cases are only used as examples to demonstrate that a strict causal tests is not consistently upheld, that instead courts are prepared to comply with demands of fairness and justice. Accordingly, these exceptional cases are discussed with a view to tracing three major challenges that this approach entails for making coherent causal inferences in the climate change context. As a special case in point for climate litigation, the decision of the Essen Court of First Instance (Landgericht Essen) in *Lluiya v RWE* is used to demonstrate that a mechanistic application of causal tests will remain insufficient.[6]

For the analytical part of this paper, we then concentrate on developing a novel matrix for causal explanations in the climate change context. The focus in that part rests on the logical fundamentals of legal causation, represented by the existing elements of necessity and sufficiency and, as will be explained and discussed in detail, a new element: sustenance. Sustenance is defined as the capacity of a factor to protect or maintain an effect despite certain structural ***52** changes in the model.[7] With this matrix, the article provides some groundwork that can be used in future judicial reasoning, especially if courts establish themselves as "cooperative courts," where "specific judgements will make novel and eminently compelling statements that a resonate in courts in other jurisdictions."[8] However, its potential use goes beyond litigation, as certainty on the threshold requirements of legally meaningful causal connections is an important prerequisite for identifying and presenting relevant scientific evidence and using this evidence not only in courts but also for advancing international and domestic law which is designed to managing climate change.[9]

The main argument we develop is as follows. There is sufficient robust evidence to establish a strong causal connection between historic and future anthropogenic GHG emissions, an increase in the global mean surface temperature and the severity and frequency of certain individual severe weather and climate related events. To capture this evidence, we introduce the term "distinctive causal field." This term thus denotes a strong causal connection between anthropogenic emissions and an increase in the likelihood and intensity of classes[10] (or types) of extreme events.

***53** Probabilistic event attribution is used to present the evidence for specific extreme events that can be attributed to certain emitters. Based on formal logic, we open the legal concept to scientific findings where a concrete climate impact can be attributed to a specific emitter.[11] This is achieved by introducing the property of "sustenance" with which Judea Pearl-- known for his theory of causal and counterfactual inference based on structural models--has revolutionised our understanding of causation across scientific and sociolegal research.[12] Sustenance is used where the logical elaborations of necessity and sufficiency alone are inadequate to fully capture cause-quality in law. It is a key notion to make causal inferences within our matrix. In the context of climate change, and potentially beyond,[13] this additional property accounts for components of a set of conditions which can be concurrent causes. The argument is developed in three parts, followed by a conclusion.

Beginning with an explanation of our use of the terms "cause" and "concurrent cause" in Part I, we briefly present some specific categories of cases where the traditional tests for causation ***54** have failed and prompted normative adjustments. We introduce the case *Lluiya v. RWE* as a specific case in point to demonstrate three main constraints that the current causal inquiry entails in climate litigation. Part II explains the recent developments and the methods in the field of probabilistic event attribution. This part explains how scientists establish specific evidence that relates the fraction of the attributable increase in the occurrence frequency and intensity of individual extreme weather and climate related (slow onset) events to certain emitters.[14] Part III joins law and climate science and introduces a thorough discussion of the criteria of necessity, sufficiency and sustenance, including previous attempts to systemically capture concurrent causes in law. We then introduce our proposal of a new matrix for causal explanations in the climate change context. This rests on three pillars, each of them addressing one of the main constraints of the current causal tests. The new matrix thus remains firmly based on the existing counterfactual inquiry but uses an extended logical basis. This allows us to reconcile probabilistic attribution and the various confidence levels which attach to the evidence, for causes that are at least concurrent causes, in a coherent concept of causation in law.[15]

II. The Current Legal Framework for Causal Analysis

Despite the fact that differences in the law apply across jurisdictions, the core idea of any causal explanation in law is that mere co-relations between factors can be distinguished from mechanisms ***55** that cause one factor to produce another.[16] We understand the term "cause" as such factor that can produce an event, without pre-selecting a deterministic or probabilistic relation between the factor and the event that follows.[17] Conversely, the term is used in a wider sense to explain that an event has been produced and a factor will qualify as "cause" of this event if it has at least increased the *probability* of the event's occurrence in a statistically significant way.[18] On that basis, a "concurrent cause" is defined as "an act or event or a state of nature which initiates or permits ... in conjunction with other causes a sequence of events resulting in an effect."[19] This captures factors that form part of a set of conditions and multi-stage scenarios where a chain of factors lead to an event.

Across most legal systems,[20] and despite many differences across jurisdictions which cannot be discussed in detail here, the core test for causation follows a bifurcated approach.[21] The first limb is factual causation, where a counterfactual inquiry seeks to identify the factor that was necessary or sufficient for the event. The ***56** second limb is finding the legally relevant cause. This involves normative considerations,[22] to establish which factor was relevant and which was not, or not to the same extent, and to elude the strictness of a mechanistic application of the test. In the next section, we trace some of the legal developments where the strictness of the causal analysis is coupled with normative correctives, along with the challenges that this presents to a coherent concept of causation. This section demonstrates that our approach is not as radical as it may seem at first instance. It ties in with the observation that pragmatic judicial reasoning surrounds the quest for causal explanations in cases where justice demands a deviation from a strict approach.

A. Resolving the Harshness of “But For” and “Conditio Sine Qua Non”--Examples Outside Climate Change

The “but for” test derived from tort law asks whether the harm would have occurred *but for* the action concerned? The “conditio sine qua non” test which is most familiar to the lawyer from a civil law tradition seeks to define the causal link based on similar counterfactual considerations. Both approaches claim to establish a causal link from a logical-scientific perspective. Using a counterfactual inquiry, the cause-quality of a factor is assessed by a process of elimination of the relevant factor in mind.[23] Consequently, every cause, that cannot be thought to be non-existent without omitting the event in question, is considered to be a factual cause.

Under the limb of legal causation, normative correctives are then applied to identify the factor that not only was necessary for the result as factual cause but is also different from other factors or mere circumstances which are not included in the consideration of the causal chain.[24] However, normative correctives are also applied to ***57** find the cause in exceptional cases where a strict test of causation would contravene law's consideration of fairness and justice.[25] The following section briefly explores some examples of this approach used in the area of the law of torts, thereby considering aspects of procedural law and substantive law that incorporate normative determinations.

Allocating the burden of proof, setting the threshold of certainty to distribute risks, and shifting the burden of proof, are normative determinations for which the procedural law can account.[26] Generally, “but for” causation in the common law of torts entails that a claimant must prove that there was more than a fifty percent chance that the breach of the duty caused the harm.[27] In other words, the action may not be the only factor that causes the type of harm but in the specific situation it must have been *the most likely* one.[28] The “conditio sine qua non” test used in civil law jurisdictions does not comprise a clear numerical threshold but requires that the court is convinced that a causal link exists.[29] Courts may also apply normative correctives which result in shifting the burden of proof,[30] or allow the claimant to prove only a substantial increase of the risk ***58** which eventually led to the harm if a material contribution to the harm itself cannot be proven.[31]

The main category of cases where the outcome of a strict causal analysis is adjusted on the basis of normative considerations consists of concurrent causes in multi-stage scenarios or variations of cumulative causation. In these cases, none of the causes on their own would satisfy the “but for” test or the theory of equivalent causation under the “conditio sine qua non” formula. This could be either in a situation of alternative sufficient causation where other single factors[32] or a set of factors could have led to the same event[33] or in a case where all factors must be present for the event to occur. The former situation of alternative causation has been clarified in some jurisdictions, so that if “multiple acts exist, each of which alone would have been a factual cause ... of the physical harm at the same time, each act is regarded as a factual cause of the harm.”[34] Accordingly, uncertainty in relation to the actual tortfeasor shifts the burden of proof onto the defendant.[35]

In the United Kingdom (UK), a very specific exception developed for the legal treatment of concurrent causes in the so-called ***59** *Fairchild* line of cases. In these cases, a normatively modified approach was established for every single instance of exposure to asbestos in consecutive employments that preceded the harm and increased its risk, even if it was not possible to prove through which specific situation of exposure to asbestos the injury (mesothelioma) occurred.[36] This was followed by legislation to clarify that for this specific category of asbestos exposure cases, all past employers who contributed to the increasing risk are severally and jointly liable, thus each of them is liable for the entire harm.[37] The *Fairchild* exception has not been extended into other areas so far.[38]

However, a further group of exceptional cases in the UK concerns the exposure of employees to harmful substances other than asbestos. Here, part of the amount of the harmful substance is considered to be "allowed" and thus, labelled as "innocent," whereas any amount above this threshold falls into the category of being "guilty."[39] If then neither the innocent nor the guilty amount alone are deemed as being able to cause the medical condition which the employee suffers, but the amounts together are on the balance of probabilities causal for the harm and thus constitute a set of conditions, it is sufficient that the "guilty" amount made a material contribution to the condition and the claimant is entitled to receive full compensation.[40]

***60** In Canada, legislation has overcome the barrier of a strict causal analysis in multi-stage scenarios involving concurrent causes in tobacco litigation. For litigation relating to the recovery of healthcare costs, causation can be established on an aggregate basis and liability is apportioned based on the market share of tobacco companies. Smoking related healthcare costs from tobacco producers can thus be recovered on the basis of specific legislation that sets forth a formula determining the market share and reverses the onus of proof.[41] A slightly different situation of cumulative causation arises when concurrent causes contributed a *certain* proportion to the harm which can be determined, for example when successive employers contributed harmful substances through insufficient working conditions. English and German legal systems will hold each of them liable in proportion to the contribution which can be measured in intensity and duration of exposure; none of the employers is liable for the entire harm.[42]

Again at a general level, the continental approach to causation is structurally similar to the common law. It introduces normative parameters for causal explanations and supplements these with further theories on the basis of statutory provisions, such as the theory of "adequate causation" and the theory of the protective scope of the statutory norm.[43] French law uses the equivalence ***61** theory combined with an explanatory theory for the concrete event.[44] Under the German Civil Code (*Bürgerliches Gesetzbuch, BGB*), much effort has been dedicated to develop a coherent theory of causation from a bifurcated normative perspective which views causation as a foundation of the existence (*Haftungsbegründend*) and the scope of the liability (*Haftungsausfüllend*).[45] For causation to be the foundation of liability, the theory of equivalence is the starting point, but this theory is not conclusive of the extent of liability. The theory of adequate causation is used to eliminate *unlikely* factors from the causal chain.[46] This probability is measured *ex ante*, from the perspective of an objective bystander.[47] A positive formulation requires that the factor must have increased the probability of any event of such a kind in a not only negligible fashion, for example harm that occurred following medical negligence in the treatment of an injury may still be considered as a consequence of the cause that made the treatment necessary in the first place.[48]

Using normative correctives and reducing or reversing the burden of proof, are the conventional methods of the law to soften the outcome of causal analysis. This facilitates a re-distribution of risk which often would not be achieved for concurrent causes on the basis of the mechanistic "but for" or the "conditio sine qua non" test.[49] However, applying these normative considerations in specific cases, all of them outside climate change, does not resolve the systemic ***62** difficulties that arise from the strict causal analysis in the context of climate change. Further, it does not account for scientific evidence forecasting the likelihood of future events based on past occurrences of similar events (for example heat waves) and case-specific evidence. This will be demonstrated in the next section.

B. Finding the Causal Link in Climate Litigation

Climate change litigation faces many obstacles, often revolving around procedural questions of standing[50] and jurisdiction,[51] but also as a consequence of applying criteria of established legal concepts--such as causation--to a new challenge.[52] This is neatly illustrated in the decision of the District Court of Essen in the case *Lluiya v. RWE*.[53] The claimant, a Peruvian farmer living in the Andes, asserts that his home and livelihood are threatened by the risk of flooding from a glacial lake outburst. The glacial lake Palcacocha is damming glacial meltwater, the water is hold by a natural moraine (deposit of irregular mass of debris from a glacier) and controlled by a set of basic pipes to reduce pressure. He claims from ***63** the German Energy provider RWE AG a pro rata financial contribution to flood protection measures in proportion to the company's GHG emissions on the basis of Art. 1004 of the German Civil Code (BGB).[54] The calculation of the compensation is derived from the report on the quantified contribution of “carbon majors” to cumulative global GHG emissions.[55] The report states that the company contributed 0.47 percent to the global total.[56] The Essen court held that RWE would not qualify as a disturber of the claimant's property in the absence of equivalent and adequate causation.[57] Applying the strict “conditio sine qua non” test of causation, the court was not satisfied that the contribution of RWE could be considered to be significant given the existence of multiple other pollutants, despite acknowledging that the company was a major emitter. However, “in the light of the millions and billions of emitters worldwide” the court was unable to conclude that anthropogenic climate change, and consequently the purported flood risks of the glacial lake, would not occur without RWE's emissions.

***64** The appeal against this judgment is currently pending in the second instance, the Regional Court in Hamm.[58] After hearing oral arguments, the Hamm court ordered evidence to be heard.[59] Under German procedural law, this means that the Hamm court is of the opinion that the case is conclusively (similar to prima facie plausibly) argued[60] and it is now a matter of providing scientific evidence to answer the specific questions asked by the court.

In contrast to the Essen court, the Australian court in *Gray v. Minister for Planning* reasoned that merely because the *concrete* contribution of certain emissions could not be accurately measured, this would not suggest that a causal link between the burning of coal and the impact on the global climate was insufficient.[61] The issue in question in that case, however, was whether a sufficiently proximate link between mining and GHG emissions, including their impact on climate change, could be established as part of an environmental impact assessment.[62] Such a situation is different from the attribution of a concrete climate change impact to not only the amount of global GHG emissions worldwide, but to a specific emitter as in *Lliuya*. It is also different from the circumstances in *Urgenda*, where The Hague District Court and The Hague Court of Appeal both found a causal link between emission intensity and the impacts of climate change,[63] or the statement of the Supreme Court of Colombia ***65** when acknowledging that multiple simultaneous causes impact the ecosystem.[64]

These decisions are not considering the causal link between an *individual* climate related event and overall GHG emissions worldwide or even attributing the event to a narrower group of emitters. They do, however, find a causal link between accumulated emissions and increasing climate change impacts generally. On that basis, the most far-reaching decision in finding a causal link between climate related events and a concrete source of emissions is *Gloucester Resources Limited v. Minister for Planning*, where the New South Wales Land and Environment Court (“NSWLEC”) posited that there is a causal link between the planned project (a new coal mining plant) and the project's cumulative GHG emissions and further climate change and its related consequences.[65] Interestingly, the court reasoned that it is sufficient that the project's emissions would “likely contribute to the future changes to the climate system and impacts of climate change” and that the project was “likely to have indirect impacts on the environment, including the climate system.”[66] Thus, the NSWLEC acknowledged a causal link in the light of the scientific treatment of corresponding uncertainty levels.

This decision is one in an increasing number of climate litigation cases, demonstrating that systemic issues remain in the application of the "but for" test of causation, when attributing specific climate related events to global GHG emissions or concrete emitters. The following section summarizes, on the basis of the case law discussed in the two previous sections, three systemic constraints of our conventional approach to test causation in the climate change context.

*66 C. Three Constraints for Causal Explanations

The existing framework of causal analysis confronts a coherent approach to causal explanations in the context of climate change with three major constraints. The first constraint is that the current approach couples a strict causal test with normative adjustments for some specific ex-post causal explanations, however, no such treatment has been devised at a comprehensive level. The harshness of the causal test is only alleviated through case-specific normative correctives--none of these have been sufficiently elaborated in the climate change context so far,[67] leaving the strict "but for" analysis as the default position in law.

The second constraint is that the existing framework lacks the means of reflecting scientific evidence that makes projections about changes in *probability* of any future weather or climate related events with various degrees of confidence levels. This ignores the potential of climate science because it undermines the underlying question of causal analysis: How could the attributed (weather or climate) event be prevented in the future? Portraying factual causation through a counterfactual enquiry necessarily compares the existing world with a counterfactual world, where higher uncertainty *is* associated with the latter. The "but for" test claims to be based on mathematical operations yet in reality is inherently limited by what we think would have happened in the absence of the event. This not only presumes we can single out one specific factor but also that the ***67** event in its concrete form occurred because of this factor. It pretends certainty where always only degrees of likelihood can exist.[68]

A third and major constraint concerns the role of concurrent causes. The "but for" test neglects a contributing factor as potential cause-candidate if it is not the only necessary or sufficient factor that is responsible for the event. The test does not provide a tool for identifying concurrent causes that are components of a set of factors, where only the set *in its entirety* is sufficient for an increased risk or harmful event, or in a situation where only a succession of events leads to the final result.

The following Part II briefly explains the emerging field of probabilistic event attribution, its methods and role in climate science, including the two levels of uncertainty treatment in reporting research results. On that basis, Part III ties law and climate science together and proposes a new matrix for causal explanations in the climate change context to address the three constraints.

III. Probabilistic Event Attribution

Causally explaining observed changes in the climate system has been the aim of a field of climate science known as detection and attribution since Hasselmann in 1997 developed methodologies to attribute observed trends in global mean temperature to known natural and anthropogenic drivers. In essence, a climate model is used to simulate global mean temperature with and without anthropogenic GHG emissions finding that without these emissions the observed increase (1°C today[69]) cannot be simulated. While traditional detection and attribution methods yield significant results only when trends are very strong, changes in the probabilities of extreme events are subtler and could thus not be attributed to global GHG emissions at the time of Hasselmann when climate models were extremely costly to run.

*68 A. Developments in a New Field of Climate Science

Today, climate science can determine that the Argentina heatwave in 2013-2014 was made five times more likely due to total anthropogenic emissions and the European Union's emissions account for an increase of thirty seven percent in the likelihood of this heat wave occurring.[70] Rapid analyses are used to produce results immediately after an extreme event has occurred, for example to explain that the 2018 heatwave in Northern Europe was made at least twice to five times more likely to occur in many places because of climate change.[71]

With the increased availability of large ensembles of climate models, a different field of detection and attribution has emerged: probabilistic event attribution. While differences in the methodology exist,[72] the main aim of this science is to answer the question whether and to what extent anthropogenic climate change has altered the likelihood and intensity of an individual extreme weather event to occur. Using climate modelling and statistical modelling, scientists estimate the probability of an event to occur with climate change ("P1") and in a counterfactual climate of a world without anthropogenic GHG emissions ("P0"), thus causally linking the occurrence probability of severe weather events to external drivers of the climate system.[73] On that basis, it is then possible to quantitatively determine even the contribution of individual countries to the changing likelihood ***69** of certain extreme weather events as a result of these countries' emissions.[74]

Results of event attribution studies are expressed in risk ratios ("RR"), calculated as the ratio between the probability of an event to occur in today's climate ("P1") and an unchanged climate ("P0"), describing the change in occurrence frequency of the event caused by anthropogenic climate change.

$$RR=P1/P0$$

Risk ratios are given with confidence intervals representing sampling and methodological uncertainties.[75] The causal statement thus entails the *identification of a cause*, such as increasing emissions, and represents a *causal quantity* in the shape of the attributable risks.[76] The design and framing of the attribution study is essential for the interpretation and any further use of results that it delivers.[77] In particular, the definition of the event that is studied is crucial. For example, defining the heatwave of 2018 as a European temperature average over the whole season June to August will result in risk ratios that are much higher compared to a more localized and impact focused definition like maximum heat stress in a city.[78]

A further significant differentiation is made between the types of events that are examined. While the Arctic heatwave in December 2016 was made more than 1000 percent more likely due to anthropogenic GHG emissions with contributions of the European Union and the United States alone doubling the risk, the rainfall event in the United Kingdom during January 2014 was made ***70** forty percent more likely by total GHG emissions and only three percent more likely as a result of European Union GHG emissions.[79] It is also important to highlight that there are extreme events that are made less likely by anthropogenic climate change while for others the risk is unchanged even in a changing climate and, crucially there are events for which current methods and tools are not advanced enough to estimate the change in risk.[80]

While for a number of studied events and variables the climate change signal[81] is relatively linear with global mean temperature increase, this is not always the case. A linear pattern has been found to exist for some regional climate change impacts; for others a quasi-exponential increase or a sigmoidal pattern of change exists.[82] This means that defining a causal relation between GHG emissions and a specific impact depends very strongly on the type of event, the region in the world and temporal and spatial scales of the studied event.

A crucial implication of the development of probabilistic event attribution is that it cannot be applied only after an event has happened and damage occurred. When vulnerabilities and thresholds are known, changing risks can be calculated *ex ante*. In other words, the changing risks can be forecasted. The improvement of the methods allows geographically very specific events to be anticipated and thus, appropriate adaptation measures can be designed.[83]

B. Uncertainty Treatment in Probabilistic Event Attribution

There are two levels where uncertainty treatment plays a role. First, the probability concerning the causal link itself, for example, ***71** the anthropogenic GHG forcing increased the likelihood of intense rainfall as measured in the wake of hurricane Harvey that hit Houston, Texas in August 2017 by a factor of 1.5 to five times.[84] Second, the confidence level that is attached to this statement; given that climate models are known to be not unbiased in representing hurricanes and only one other independent study with similar findings exists, the confidence in this statement (on Hurricane Harvey) is only medium.[85]

These two levels of uncertainty are independent of whether a projected (ex-ante) or attributed (ex-post) change in the occurrence frequency of an extreme event is large or small. For example, we have *high confidence* that anthropogenic climate change increased the likelihood of extreme precipitation in UK winters by forty percent (*likely* range 0-100%) while we have *medium confidence* that the 2015-2017 drought in Cape Town was made three times more likely (*likely* range factor 1.4 to 6.4).[86] The likelihood statements result from statistical analyses of climate data whereas the levels of confidence depend on the climatic variables (temperature, precipitation, pressure, etcetera) analysed, availability and quality of observed ***72** data, strength of theory describing and understanding processes in the climate system, reliability of climate models and the availability of evidence (number of scientific studies as well as number of independent data sources).

How can the increase in risk for which probabilistic event attribution provides the evidence be captured in a standardised causal law? If there are other cumulative factors that contributed to an event and increase the likelihood of the future occurrence of similar events of this kind, but none of the factors passes the traditional threshold set by the "but for" test, is it possible to find a causal explanation? Intuitively, the answer might be positive, however, a more rigorous structural causal law exists and this will be developed in the following part.

C. Three Pillars for Analysis in a New Matrix on Causation

The following part develops a model that addresses the three constraints of the conventional test of causation as discussed in Part I, making use of probabilistic event attribution as introduced in Part II. The model is based on Pearl's explanation of his theory of causation, which is grounded in logical elaborations of the notions of "necessary" and "sufficient" conditions and complemented by "sustenance" as a final element. The model comprises three pillars.

The first pillar is derived from the logical elaborations of the notions of "necessary" and "sufficient" conditions,[87] which already underlie the legal concept of causation, to identify relevant factors of the causal chain. The strength of the causal connection between these factors is then determined on the basis of the degrees of probability and the confidence levels with which scientific results are reported for each of these factors.[88] The transitivity theory is applied as a mathematical tool to reflect the logical consequences that the ***73** existence and the related strength of a causal link across factors in a multi-stage scenario entails.

The second pillar accounts for climate science, including probabilistic event attribution, to demonstrate that higher amounts of GHG emissions increase the intensity and frequency of climate related events. We introduce the notion of the *distinctive causal field* to capture this strong connection where sufficient event-specific evidence for a plurality of types of events exists.

The third pillar supplements the existing logical fundamentals with the notion of "sustenance" to offer a coherent approach to causal explanations in the climate change context that includes concurrent causes. Probabilistic event attribution is used to explicate the fraction of the attributable risk for a cause that is at least a concurrent cause.

i. Necessary and Sufficient Causation

A causal relation between different factors and the degree of confidence that allows concluding from one factor to the existence of another, are regularly established using the criteria of "necessity" and "sufficiency." This reasoning already forms the basis of our legal concept. It is concerned with providing proof at every stage of the structural chain of events that the premises imply a certain conclusion.[89]

The following explains causation as a fundamental logical concept, based on the relation between two factors, we call them at this stage "N" and "S." S is a sufficient condition for N if it is true if there is S, we know that there is also N. It is possible to say that S implies N, or whenever there is S, then N is also true. That does not imply that N will *only* be true if there is S: N may also occur in the absence of S, where another factor leads to N. However, S cannot be true without N being present, because N is necessary for S. If we ***74** could establish that N will only be true in the case if S is present, we could conclude that N and S are equivalent conditions, where both are sufficient and necessary for each other at the same time. Such an equivalent relation between N and S indicates a very strong causal connection.

The law does not always explicitly discuss necessity and sufficiency and it does not require an equivalent relation to establish the "actual cause." However, the counterfactual "but for" test reflects the strong influence of the necessity element to establish causation in law and consideration to the sufficiency element is given in cases where one main factor lead to the event in question.[90] Causal claims on the basis of necessary and sufficient conditions can be made in varying shades, depending on the evidence that is available. High levels of confidence and event-specific evidence explicate a strong causal connection between two factors.[91]

In returning to our climate change context, we now establish the causal connection on the basis of these two existing logical fundamentals, between the following four factors that climate scientists identify in the multi-stage scenario of anthropogenic climate change: "E," "T," "I_F," and "I_S". These will be explained in turn. E denotes the quantity of anthropogenic GHG emissions.[92] T stands for the increase of global mean surface temperature. I_F captures the impacts of a changing climate consisting of a general tendency of increasing *frequency and severity* of some weather events and (climate related) slow onset events. I_S denotes the occurrence of a *concrete* climate change impact, either a severe weather event or a slow onset event.

If there is to be a causal link between a concrete climate impact I_S (for instance severe flooding, a specific heatwave or a hurricane) and E, explaining the relations between and E and T, between T and I_F and E and I_F are key steps for the investigation whether I_S could have been anticipated (and thus avoided) and we ***75** proceed with this before turning to the direct link between E and I_S, for which attribution science can now also provide the scientific evidence.

Further, a binary relation over a set of factors can generally be qualified as a transitive composition of binary variables, if a chainlike process exists where it is true that "X causes Y and Y causes Z regardless of X, it can be concluded that X causes Z."[93] From our understanding of processes in the atmosphere, observational analyses and climate modelling, we know that the occurrence of extraordinary global-scale heat waves, some extreme precipitation events,[94] droughts and storms in some areas,[95] cannot be explained without human-induced climate change.[96] These impacts of climate change I_F, allow us to identify E as cause for I_F where there is a transitive relationship between E, T, and I_F. If the relation between E and T and T and I_F is transitive that means that E is also and *in the same way* related to I_F. To put it differently, this establishes a causal link between GHG emissions and the general increase in frequency and severity in climate change impacts. Transitivity also maintains the strength of the causal relation over the entire set of factors.

Consequently, if we establish a causal relation between an increase of E and the increase in T and the increase in T and increasing frequency and severity of climate change impacts I_F, a causal relation between the increase of E and I_F can also be determined. Depending on the strength of the causal explanation (the level of confidence), this thus allows us to anticipate I_S where I_S a narrower defined event comprised within I_F. The following part ties in the ***76** scientific evidence between E, T and I_F before then taking a closer look at the relation between E and I_S.

There is sufficient scientific evidence that the present increase in T would not have happened without the increase in E[97] and more than ninety seven percent of actively publishing climate scientists agree.[98] The evidence for the relation between E and T has grown further in the last decade and the confidence level is expressed as *virtually certain* for the human influence as the dominant cause of the observed warming since the mid-twentieth century.[99] Cumulative total GHG emissions and the response of T are approximately linearly related.[100] The contribution of E to the increase in T was likely to be in the range of 0.5°C to 1.3°C during the period 1951 to 2010 and is approximately 1°C today.[101]

This means that between the increase in E and the increasing T exists even an equivalent relation. Both are necessary and sufficient conditions for one another. Increasing E is a necessary condition of the increase of T since 1880. T would not have occurred without E and E is also a sufficient condition for T, because this very concrete temperature increase is a consequence of E. No other factor explains the increase in T.

Scientific evidence further shows that an increase of T implies the occurrence of some more intense and more frequent severe weather events and slow onset events.[102] There has been further ***77** strengthening of the evidence for human influence on the frequency and intensity of daily temperature extremes since the mid-twentieth century, and it is very likely that a human induced increase in average mean temperatures has more than doubled the probability of occurrence of heat waves in some locations.[103] Changes in many extreme weather and climate events have been observed since about 1950.[104] Slow onset events, such as glacial retreat, can be measured globally and over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (high confidence).[105]

Up to this point, a strong causal connection can be demonstrated in the form of equivalent causation between E and T and between T and I_F as a *general trend, or expected consequence*, which means that E and I_F are also both, necessary and sufficient conditions in accordance with the transitivity theory. It is correct to say that E implies I_F, E and I_F display an equivalent relation and thus a very strong causal connection.

ii. Distinctive Causal Field

We introduce the notion *distinctive causal field* to capture this strong connection between E and I_F, where I_F is the general trend of extreme weather and climate related events for which sufficient event-specific evidence for a plurality of similar climate events (for example heat waves) exists. The term *causal field* was first introduced by Anderson and revived by Mackie to explain that all causal claims are made in a certain context, for instance against the ***78** background of certain theories or a set of facts which are considered to be common, in order to identify the one factor that was different from the causal field on a particular occasion.[106] The term *distinctive causal field* is used here in a slightly modified version, influenced by the view of Lewis on events that share a common causal history,[107] to describe the general context of expected events within which causation of a single climate related impact is examined.

In addition to using the causal explanation between E, T and I_F to understand the likelihood of I_S as just demonstrated, the causal link between E and I_S can now be established directly using probabilistic event attribution. Thus, changes in E lead directly to impacts as well as via the increased T and the direct link between E and I_S can be observed and measured in accordance with this new scientific evidence. These impacts concern changes in the likelihood and intensity of extreme weather events, such as heat waves in large parts of Europe, Asia and Australia and an increased frequency or intensity of heavy precipitation events in North America and Europe.

Further impacts include slow onset events such as changes in Northern Hemisphere March-April (spring) average snow cover; the reduction of the extent of Arctic July-August-September (summer) average sea ice with average temperature anomalies exceeding widely 2°C and 3°C in places;[108] changes in global mean upper ocean (0-700 meters) and global mean sea level rise.[109] The next section accounts for this new scientific evidence in the specific relation between E and I_S. It introduces the notion of sustenance to portray E as "concurrent cause" for I_S in law.

iii. INUS Condition, NESS Condition, Sustenance

The scientific evidence that establishes an equivalent relation between E and I_F encompasses a strong causal connection for all events that form part of the distinctive causal field. The existence of this distinctive causal field is important for assessing future risks ***79** using climate modelling and socioeconomic scenarios[110] and for the anticipation of structurally similar events. In addition, as discussed, attribution science identifies E as a cause-candidate in climate modelling for impacts I_S where E is directly linked to I_S. But if E is only part of a set of other factors and not the dominant cause, the law lacks the capacity to respond to these scientific findings. Thus, how can the increase in risk for which probabilistic event attribution provides the evidence, be captured in a standardized causal law, for example to explain causation in our case *Lluiya v. RWE*?

In the literature on formal logic, a variety of concepts have been discussed to find a structural causal law that accounts for concurrent causes in multi-stage scenarios. Mackie contended that a cause is at a minimum an "Insufficient, but Non-redundant part of an Unnecessary but Sufficient condition," he calls this an "INUS" condition.[111] His explanation of "cause" reflects Mill's idea of defining the cause as "the sum of the total of the conditions positive and negative."[112] Mackie's famous example is that even though an electrical short-circuit causes a fire, it is an insufficient condition on its own, because other conditions such as oxygen are needed in addition, it is non-redundant, because in this concrete instance it produced the spark. A fire can start without electrical short-circuit, it is thus unnecessary, but the *whole set* of conditions on this occasion was sufficient to start the fire.

Assuming that E is insufficient for a concrete I_S, for instance a tropical cyclone, E could still be an insufficient but non-redundant part of an unnecessary condition which is *in its entirety* sufficient on this occasion-- cyclones have happened in the absence of E--but for a concrete occurrence of a particular cyclone, E could participate as *part* or of the sufficient condition.

In *Lliuya*, if E would only qualify as part of a set of sufficient conditions, it could entail that E does not pass the test for equivalent or "but for" causation, even if it increases the risk, as was the result of the causal analysis of the Essen court. The influence of ***80** the causal risk factor E depends on the prevalence of complementary causes in a set that together represents the sufficient cause.[113] In the current framework of causal analysis, as demonstrated by the Essen court, a strict test does not reflect the contribution of the concurrent cause. Only *ex post*, that is if the risk materializes, could normative parameters (if available and applicable) be used to portray that I_S (in the example a glacial lake outburst) was partially caused by E.

Conversely, the INUS condition provides a minimum threshold for causation, which so far has been occupied solely by the requirement of the cause being a necessary or sufficient condition under the "but for" veil which creates the need for further normative corrections as discussed above. Should INUS conditions be included in developing legally meaningful explanations in the context of climate change impacts? An earlier attempt to translate INUS conditions into a legal threshold was undertaken by Wright who diagnosed an urgent need of repair of causation in the law of torts and developed the Necessary Element of a Sufficiency Set ("NESS") test. Like the INUS test, the NESS test subordinates the necessity element under the sufficiency element of causation.[114] It offers a better explanation than the "but for" test, however, sharing the same ontological framework as Mackie's INUS condition means that the NESS test is susceptible to the same criticism.[115]

Pearl agrees with the tests set forth by INUS and NESS in so far as he claims that the sufficiency component should be given additional weight in law as it draws the attention to the consequences of one's action.[116] At the same time, he confronts Mackie's INUS condition and its NESS relative with strong criticism, which is echoed by others in the discourse on formal logic. The major flaw that Pearl identifies is that it is impossible, without further limitations, ***81** to extrapolate from INUS and NESS conditions a structural-causal law that distinguishes between formulae that represent stable mechanisms and those that represent circumstantial conditions.[117] If such a standard logical syntax cannot be derived from INUS or NESS conditions, he argues that no causal law allowing for causal generalization can exist.

Jaegwon Kim--known for his research on the metaphysics of causation--proposes a way to resolve this shortcoming.[118] He calls for entities that possess both, an element of generality and an element of particularity; the former is necessary for making sense of the relations of necessity and sufficiency, and the latter for making sense of singular causal judgments. In the specific situation of climate change, this could be applied by comparing the *ex ante* causal explanation (forecast or projection) with the *ex post* causal explanation (attribution). Or to be more concrete, to focus on those events where the impacts that occurred, instantiate specific impacts I_S that qualitatively follow our expectation and forecast for I_F.

However, that would on the one hand limit the causal analysis to cases where the risk indeed has materialized and harm is suffered (and thus further entertain a bifurcated conceptual approach to causation) and on the other hand also exclude cases where no projections are available for I_S despite the existence of I_F and the fact that the event in question represents a structurally similar instantiation of this distinctive causal field.

Pearl resolves the problem by adding a further component which ties in with the counterfactual approach. Following on from what Hall calls dependence (similar to necessity) and production (close to sufficiency), Pearl introduces the notion of sustenance to supplement the counterfactual analysis.[119] Sustenance measures the capacity of the cause to *protect or maintain* the effect under structural changes in the model.[120] It translates the idea of Lewis on ***82** “quasi dependence” into a syntax where contingencies are modified to test the resulting effect and thus, the ability of the factor to sustain it.[121] Pearl translates the causal law into a mathematical formula:

“W” is in the following a set of variables which form part of a climate model, and let “w,” “w”' be specific realizations of these variables. The set of variable represents our (modelled) world u. We say that x causally sustains y in u relative to contingencies W = w, w' if and only if

(i) $X_{(u)} = x$;

(ii) $Y_{(u)} = y$;

(iii) $Y_{xw(u)} = y$ for all w; and

(iv) $Y_{x'w'(u)} = y' \neq y$ for some $x' \neq x$ and some w'.

The sustenance feature is represented in (iii). It means that x will maintain y even if we set W to any value w. (iv) explains that only x will sustain y. Thus, if we change x to x', then Y will relinquish the current value y (we could also say the effect will change), for at least one setting of W = w'.[122]

We define as follows:

$x=E$,

$Y=I_S$

W= a set of conditions, with w being variables of the set

U=our (modelled) world.

E is a cause if it will sustain I_S even if w will change. For instance, the fraction of the risk that is attributable to GHG emissions for the risk of flooding remains stable in proportion to the amount of GHG emissions, even if conditions (w) of the model are changed, such as improving flood protection measures. While the overall risk of flooding may change, the proportion of this risk that is produced by E remains the same. Only if we change E, for ***83** instance lower emissions, then there will be at least one set of conditions where I_S will change (the risk of flooding decreases).

This formula reflects the modelling used in probabilistic event attribution, where the divergence between counterfactual worlds and the actual world are simulated by changing contingency factors, such as changing emissions to measure the effect on the climate and the occurrence of climate related events. It can also be used in law, since it is based on logical fundamentals to which our legal concept can adapt. The reasoning based on necessity and sufficiency is extended by a further factor which accounts for a concurrent cause that produces the effect without being necessary or sufficient on its own.

A structural analysis using all three elements for the analysis can thus supply causal information derived from climate models. In our example case *Lluiya*, the first step is to establish the causal link between E and I_F, in this case the concentration of GHG emissions in the atmosphere and the general increase in frequency and intensity of glacial ice loss. E can be identified as part of the component factors and the contribution to the risk can be quantified, based on the knowledge of the impact of E on glaciers within I_F, climate modelling and additional case-particularistic information.[123] A specific model could then be chosen to establish further case-particularistic evidence for the relation between E and I_S. Here, E may be one factor that forms part of a set of factors that cause the immediate risk, and if E is producing the proportional increase in risk for variations of other factors it is true to say that E sustains I_S. Further, only E will sustain I_S if a change of E (defined as a change from x to x' in step iv) will change our event I_S for at least one setting of conditions (w) in the climate model. The causal statement will at every stage include a reference to the fraction of the attributable risk for I_S and the confidence levels that is attached to the scientific evidence. Thus, much will depend on the availability of scientific evidence ***84** and the strength of this data varies for different climate related events and regions.

The advantage of the here presented formula is that this causal account does not stipulate an entire new counterfactual world in which no climate impacts exist. Conversely, it asserts that it is possible to structurally change some factors of the world which constitutes the model, and to see if the studied climate event is still maintained. This limits the counterfactual analysis to certain factors and the knowledge about the real world--and the type-level impacts that constitute the distinctive causal field can be used for the modelling. Sustenance establishes causation even if the anthropogenic increase in GHG concentrations represent only a (potentially small) part of a set of conditions.

In a further and final step, E can then be more narrowly defined as only the European Union's GHG emissions or the emissions of a major carbon emitter. On that basis, the concrete contribution of (a more narrowly defined) E can be quantified. The calculated fraction of the attributable climate risk to the defined emitter can be articulated in law: it is at least a concurrent cause.

IV. Conclusion

This article has used elementary tools of formal logic to build a novel matrix of causally explaining the relation between GHG emissions and climate change impacts. We offer an approach that allows making causal statements in law about the physical reality of climate phenomena, side by side with probabilistic evidence that defines the relations between factors and events of our changing climate.

There is robust evidence that an equivalent causal relationship exists between the increase in GHG emissions due to the burning of fossil fuels and the increase in severity and frequency of certain severe weather and climate related events. These events constitute a distinctive causal field. In addition to that, the property of sustenance is key to portraying the cause-quality of the anthropogenic emissions factor in a multistage scenario with several causes forming a set of conditions, where the mechanistic "but for" or ***85** "conditio sine qua non" tests would fail in finding a cause even though a factor contributed to the event; a situation for which case-specific normative correctives have not yet been developed. The novel matrix is thus based on necessity, sufficiency and sustenance.

We have demonstrated that based on this extended logical causal analysis, the concept of causation in law is compatible with scientific uncertainties and the complexity of anthropogenic climate change. Our approach of opening a seemingly strict causal test to include sustenance as a further analytical property, is based on the observation that normative correctives influence the identification of the "actual cause" in other areas of law; in fact, pragmatic judicial reasoning surrounds the quest for causal explanations. Indeed, concentrating on causation as a pre-determined rigid concept is one of the greatest impediments for the legal response to climate change and law's capacity to use scientific evidence. It limits options on adaptation and risk preparedness,[124] and it reduces the adjudicative capacity of courts.[125]

Conversely, identifying legally meaningful causal explanations has several implications. It contributes, but is not limited, to building the adjudicative capacity of courts challenged by climate litigation. It also has a much wider impact for the potential of developing a "duty of care" of GHG emitters and influencing future legal developments under the 2015 Paris Climate Agreement. Given that sufficient data will not be available for all climate related events and risks and those data are particularly limited in the most vulnerable countries, leaving causal explanations to be tested in courts alone raises ethical concerns such as equal access to justice. Thus, ***86** the legal-political realm might be well advised to utilize causal explanations *de lege ferenda*.

Footnotes

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1 Fairchild v. Glenhaven Funeral Services [2002] UKHL 22, [2003] 1 AC (HL) 32 ("On occasions the threshold 'but for' test of causal connection may be over-exclusionary. Where justice so requires, the threshold itself may be lowered. In this way the scope of a defendant's liability may be extended."); *see also March v Stramare (E & MH)* (1991) 171 CLR 506 ("[there are] convincing reasons precluding its adoption as a comprehensive definitive test of causation in the law of negligence.").

2 United Nations Framework Convention on Climate Change art. 1(2), Mar. 21, 1994, 1771 U.N.T.S. 107 (defining climate change as a "change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."); United Nations Intergovernmental Panel on Climate Change, Special Report: Global Warming of 1.5°C 544 (2018) (referring to climate change as "a change in the state of the climate that can be identified ... by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.").

3 Friederike E.L. Otto et al., *Assigning Historic Responsibility for Extreme Weather Events,* 7 Nature Climate Change 757, 758 (2017).

4 *See* Michael Strevens, Depth: An Account of Scientific Explanation 6 (2008); Wesley C. Salmon, *Statistical Explanation*, *in* Robert G. Colodny, The Nature and Function of Scientific Theories 173 (1970); Patrick Suppes, A Probabilistic Theory of Causality 12 (1970); Michael S. Moore, Causation and Responsibility: An Essay in Law, Morals and Metaphysics 3 (2009). We will not focus on the Bayesian interpretation of probability; for an introduction into the Bayesian theorem, *see* Judea Pearl, Causality 2 (2d ed. 2009); For an excellent discussion of the use of the Bayesian theorem and probabilities in jurisprudence *see* Adam Perry, Strained Interpretations (Feb. 11, 2019) (unpublished manuscript), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3175410.

5 Ernest J Weinrib, *Causal Uncertainty,* 36 OJLS 135, 140 (2016), draws the attention to conceptual operations in handling causal uncertainty in accordance with corrective justice; Emmanuel Voyiakis, *Causation and Opportunity in Tort*, 38 OJLS 26, 28 (2018) explores and extends Hart's and Scanlon's insights about the justificatory significance of alternative options; for the differentiation between statistic and causal inferences, see Richard W Wright, *Causation, Responsibility, Risk, Probability, Naked Statistics, and Proof: Pruning the Bramble Bush by Clarifying the Concepts,* 73 Iowa L. Rev. 1001 (1988); Patrick Shaunessy, *A matter of choice: rethinking legal formalism's account of private law rights,* 37 OJLS 163 (2017); further on the explanatory power of economic analysis: William Landes & Eric Posner, The Economic Structure of Tort Law 23 (Harvard 1987); Guido Calabresi, *Concerning Cause and the Law of Torts: An Essay for Harry Kalven Jr.,* 43 U. Chi. L. Rev. 69 (1975); Richard Epstein, *Causation and Corrective Justice: A Reply to Two Critics,* 8 J. Legal Stud. 477 (1970); Joseph Gardner, *What is tort law for? Part 1: the place of corrective justice,* 30 Law & Phil. 1 (2011); Gregory Mitchell & Philip Tetlock, *An empirical inquiry into the relation of corrective justice to distributive justice,* 3 J. Empirical Legal Stud. 421 (2006).

6 Landgericht Essen [District Court Essen] Dec. 15, 2016, 2 O 285/15 (Ger.).

7 Pearl *supra* note 4, at 309, 316, 317; The element of sustenance, including the mathematical formula that expresses it and underlies the analysis, will be discussed in detail in 3.3.

8 Eyal Benvenisti, *Reclaiming Democracy: The strategic Uses of Foreign and International Law by National Courts*, 102 Am. J. Int'l L. 241, 251 (2008). A good example of this mechanism is the order of the Australian Land and Environment Court with references to the *Urgenda* decision of The Hague Court of Appeal, see *Gloucester Resources Limited v Minister for Planning* [2019] NSWLEC 7 (Austl.); for the Dutch Judgment, see *The State of the Netherlands v Urgenda Foundation* 200.178.245/01 (9 Oct. 2018) ECLI:NL:GHDHA:2018: 2610 (unofficial English translation); for a discussion, see Petra Minnerop, *Integrating the 'Duty of Care' under the European Convention on Human Rights and the Science and Law of Climate Change: the Decision of The Hague Court of Appeal in the Urgenda Case*, 37 J. Energy & Nat. Res. L. 149, 174 (2019).

9 1/CP.21 UN FCCC/CP/2015/10/Add. 1, Paris Agreement, Article 2(2).

10 An example of a class of events is a heat wave at least as hot, or hotter, than the one observed in 2014 defined over the whole country of Argentina; A class of events is thus not a singular event but all the events that lead to similar or worse impacts in a certain geographical area or sector.

11 *Formal logic* is understood here in a mathematical sense, where mathematical techniques and laws (such as the transitivity theory) are used to develop a valid legal argument. For a definition of logic, see Elliott Mendelson, Introduction to Mathematical Logic xv-xix (6th ed. 2015); *see also* Patrick Suppes*,* Introduction to Logic xviii, 253 (1964). Semantics or logical syntax are terms used by philosophers to denote a structured and formalised mathematical theory (metamathematics). The use of formal logic is based on the understanding that the concept of causation in law is indeterminate and this cannot be resolved by legal interpretation alone, see Judea Pearl, *Causes of Effects and Effects of Causes*, 44 Soc. Methods & Res. 149, 152 (2015); *see* David W. Robertson, *The Common Sense of Cause in Fact*, 75 Tex. L. Rev. 1765 (1997). Sometimes further criteria must be added to resolve legal indeterminacy; see Thomas Endicott, *Interpretation and Indeterminacy: Comments on Andrei Marmor's Philosophy of Law* 10 Jerusalem Rev. Legal

Stud. 46 (2014). The complexity of a societal problem can be addressed through adding further connecting elements within a given system, see Niklas Luhman, Die Gesellschaft der Gesellschaft 137, 996 (1998).

12 Pearl, *supra* note 4, at 316, 317.

13 The claim that the legal argument is well reasoned can be limited to a particular legal order or a legal concept constituting the referential framework, however, a more general claim that the legal argument is reasonable beyond this partial framework is not excluded, see Robert Alexy, Theorie der juristischen Argumentation 351 (1986).

14 Slow onset events include the temperature increase, sea level rise, desertification, glacial retreat and related impacts, ocean acidification, land and forest degradation, salinization and loss of biodiversity.

15 This contributes to the role of law in addressing climate change. The UN Special Rapporteur on extreme poverty and human rights identified climate change as a threat to the rule of law and democracy, Special Rapporteur on Extreme Poverty and Human Rights, *Visit to the United Kingdom of Great Britain and Northern Ireland*, ¶ 65, U.N. Doc. A/HRC/41/39 (June 25, 2019); Elisabeth Fisher & Eloise Scotford, *Climate Change Adjudication: The Need to Foster Legal Capacity: An Editorial Comment* 18 J. Envtl. L. 3,4 (2016).

16 Strevens, *supra* note 4, at 7. Causal explanations thus differ from statistical explanations, *see* Salmon, *supra* note 4, at 173; Suppes, *supra* note 4, at 12.

17 Ernest Sosa, *Varieties of Causation*, *in* Causation 234 (Ernest Sosa & Michael Tooley eds. 1993).

18 Strevens, *supra* note 4, at 7, 8.

19 Kenneth J Rothman, *Causes*, 201 Am. J. Epidemiology 587, 588 (1976). The term concurrent cause is thus used here in line with judgment in the case Certain Activities carried out by Nicaragua in the Border Area (Costa Rica v. Nicar.), Judgment, 2018 I.C.J. Rep. (Feb. 2) (using the term concurrent cause where the ICJ for the first time in its history adjudicated compensation for environmental damage).

20 H.L.A. Hart & Tony Honoré, Causation in the Law 100, 108, 431 (1985) (2nd ed. OUP 1985); Desmond M. Clarke, *Causation and Liability in Tort Law*, 5 Jurisprudence 217 (2014). We do not claim to give a complete comparative analysis, the following only demonstrates the approach where a strict causal test is coupled with making normative adjustments. For a recent discussion of different theories pertaining to tort law, see John Murphy, *The Heterogeneity of Tort Law*, 29 Oxford J. Legal Stud. 455 (2019).

21 *See* Causation in European Tort Law 4, 590 (Marta Infantino & Eleni Zervogianni eds. 2017); Walter van Gerven et al., National, Suprantional and International Tort Law 395 (2000); Margaret Beazley, *Damage*, *in* Fleming's The Law of Torts 225, 227 (Carolyn Sabbideen & Prue Vines eds., 10th ed. 2011).

22 Gerven et al., *supra* note 21, at 395.

23 *Id.* at 443.

24 Moore, *supra* note 4, at 118; Jane Stapleton, *Choosing What We Mean by "Causation" in the Law,* 73 Mo. L. Rev. 433, 455 (2008); John S. Mill, A System of Logic: Ratiocinative and Inductive Volume 1 365 (2011) ("it is very common to single out one only of the antecedents under the denomination of Cause, calling the others merely Conditions.").

25 Wex S. Malone, *Ruminations on Cause-in-Fact* 9 Stan. L Rev. 60, 64 (1956); Richard W Wright, *Causation in Tort Law*, 73 Calif. L. Rev. 1735, 1743 (1985).

26 Restatement (Third) of Torts §§ 26, 441 (Am. Law Inst. 2000).

27 Kristy Horsey & Erika Rackley, Tort Law 249 (5th ed. 2017) 249.

28 Wilsher v. Essex Area Health Auth. [1988] AC 1074, 1091 (HL); Bonnington Castings Ltd. v. Wardlaw [1956] AC 613 (HL).

29 Grundsatz der freien Beweiswürdigung (principle of independent judicial evaluation of evidence), *see* Heinz Thomas & Hans Putzo, Zivilprozeßordnung (25th ed. 2003) § 286; Bundesgerichtshof [BGH] [Federal Court of Justice] Neue Juristische Wochenschrift [NJW] 2000, 953.

30 In the Mesothelioma cases, a normatively modified approach to factual causation was established for every single instance of exposure to asbestos in consecutive employments that preceded the harm and increased its risk, even if it was not possible to prove through which specific situation of exposure to asbestos the injury (Mesothelioma) occurred. This results in a reversal of the onus of proof, where the defendant has to rebut the assumption that his action increased the risk, with the increase in risk being treated as the damage.

31 McGhee v. Nat'l Coal Bd. [1973] 1 WLR 1, 4, 8; Leigh v. London Ambulance Servs. NHS Trust [2014] EWHC 286 (QB) [28].

32 *See* Baker v. Willoughby [1970] AC 467; McGhee v National Coal Board [1973] 1 WLR 1; *March v Stramare E & MH Pty Ltd* (1991) 171 CLR 506 (Austl.).

33 So called "multiple sufficient causal sets." The availability of evidence for the causal explanation of the event will decide which factor or set of factors has to be regarded as cause. *See* Restatement (Third) of Torts §§ 26, 420. Bürgerliches Gesetzbuch [BGB] [Civil Code], § 830 (setting forth the rule that where several persons participate in a course of conduct which is potentially dangerous to others, even if not as such unlawful, all actors are liable for the full extent of the damage.).

34 Restatement (Third) of Torts §§ 26, 452.

35 Bürgerliches Gesetzbuch [BGB] [Civil Code], § 830 (stating that the defendants can be held liable jointly and severally when the identity of the actual tortfeasor or the share of the contribution cannot be determined.). *See also* HR 9 oktober 1992, NJ 1994, 535 m.nt (Van Ballegooijen/Bayer Nederland BV) (Neth.) (confirming the applicability of Article 6:99BW (Buergerlijk Wetboek) in mass tort cases.). *See* Sindell v. Abbott Labs., 607 P.2d 924 (Cal. 1980) (market share doctrine). *See* Brown v. Superior Court, 751 P.2d 470, 486 (Cal. 1988) (limited liability to several only, not jointly, in DES cases).

36 Fairchild, [2002] UKHL 22 (Lord Nicholls of Birkenhead). This exception has not been extended so far, Ministry of Defence v. A.B. and others [2012] UKSC 9; Sienkiewicz v. Greif (U.K.) Ltd [2011] UKSC 10.

37 *See* Barker v. Corus U.K. Ltd. [2006] UKHL 20 (establishing only several liability based on the proportion of the attributable risk.); *See* Compensation Act 2006, 29 § 3(2)(b) (U.K.) (making provision for joint and several liability.).

38 Jones & Ors v. The Sec'y of State for Energy & Climate Change [2012] EWHC 2936 (QB); Ministry of Defence [2010] EWCA (Civ) 1317 (dismissing appeal by a slim majority); *See also* Williams v. Bermuda Hosps. Bd.[2016] UKPC 4 [hereinafter Bermuda].

39 Bonnington Castings Ltd. v. Wardlaw [1956] AC 613 (HL) (ruling that where only part of the inhalation of dust was attributable to a breach of a duty, the defendant will be liable on the ground that his breach of duty made a material contribution to the disease).

40 Bailey v. Ministry of Defence [2008] EWCA (Civ) 883; Bermuda; John v. Cent. Manchester & Manchester Children's Univ. Hosps. NHS Found. Tr. [2016] EWHC 407 (QB); *Compare* Carder v. The Univ. of Exeter [2016] EWCA (Civ) 790 (confirming only negligible contribution); *Compare* Wilsher v. Essex Area Health Auth. [1988] AC 1074, 1091 (HL) (assessing a case where there are other "innocent" causes and any of these could have led to the harm).

41 Tobacco Damages Recovery Act, S.B.C. 1997, c. 41 s. 13 (Can.), *amended by* SBC 1998, c. 45 (Can.), *repealed by* Tobacco Damages and Health Care Costs Recovery Act, SBC 2000, c. 30 s. 6 (Can.); *See* Martin Olszynski, et al., *From Smokes to Smokestacks: Lessons from Tobacco for the Future of Climate Change Liability*, 30 Geo. Envtl. L. Rev. 1, 12 (2017).

42 Holtby v. Brigham & Cowan (Hull) Ltd. [2000] 3 ALL ER 421; McGhee v. Nat'l Coal Bd. [1972] 3 ALL ER 1008; Otto Palandt, Bürgerliches Gesetzbuch § 249 (77th ed. 2018); Bundesgerichtshof [BGH] [Federal Court of Justice] June 16, 1959, BGHZ 30, 203 (Ger.); *see also* Gerven et al., *supra* note 21, at 432.

43 Münchner Kommentar zum Bürgerlichen Gesetzbuch, Band 2 Schuldrecht Allgemeiner Teil I § 249 (2019) [hereinafter Münchner Kommentar]; Christian Von Bar, The Common European Law of Torts: Volume Two (2000).

44 Gerven, *supra* note 21, at 396.

45 Münchner Kommentar, *supra* note 43, at § 249; Gerven, *supra* note 21, at 396.

46 Hart & Honoré, *supra* note 20, at 465.

47 Münchner Kommentar, *supra* note 43, at § 249.

48 Palandt, *supra* note 42, at § 249; The more complicated negative formula eliminates a factor as candidate for an adequate cause for the damage if it could produce the result in question only under particularly unique and quite improbable circumstances to which no attention would be paid if events had followed the normal course. A similar probabilistic element exists in the common law system, where under the test of the 'remoteness of damage' the criteria for 'reasonable foreseeability' assumes the perspective *ex ante*, Overseas Tankship v Morts Dock Engineering (The Wagon Mound No 1) [1961] AC 388; Jolley v Sutton London Borough Council [2000] UKHL 31.

49 Münchner Kommentar, *supra* note 43, at 416.

50 Case T-330/18, Carvalho v. Parliament, 2019 E.C.R. 324 ¶ 54 (reasoning that the applicants were not individually concerned).

51 Am. Elec. Power Co. v. Conn., 564 U.S. 410 (2011); Native Vill. of Kivalina v. ExxonMobil Corp., 696 F.3d 849, 858 (9th Cir. 2012), *cert. denied*, 569 U.S. 1000 (2013); Comer v. Murphy Oil USA, 607 F.3d 1049 (5th Cir. 2010); Bundesverwaltungsgericht Nov. 27, 2018, A-2992/2017; Jacqueline Peel, *Issues in Climate Change Litigation*, 1 Climate Change L. Rev. 15, 16 (2011).

52 *See* Geetanjali Ganguly et al., *If at First You Don't Succeed: Suing Corporations for Climate Change*, 38 Oxford J. Legal Stud. 841 (2018); Jacqueline Peel & Jolene Lin, *Transnational Climate Litigation: The Contribution of the Global South*, 113 Am. Soc'y Int'l L. 679 (2019); Sophie Marjanac & Lindene Patton, *Extreme Weather Event Attribution Science and Climate Change Litigation: An Essential Step in the Causal Chain?*, 36 J. Energy & Nat. Resources L. 265 (2018); Jacqueline Peel et al., *Shaping the 'Next Generation' of Climate Change Litigation in Australia*, 41 Melb. U.L. Rev. 793 (2017); Jacqueline Peel & Hari M. Osofsky, *Climate Change Litigation's Regulatory Pathways: A Comparative Analysis of the United States and Australia*, 35 L. & Pol'y 150 (2013); Jolene Lin, *Climate Change and the Courts*, 32 Legal Stud. 35 (2012); Brian J. Preston, *Climate Change in the Courts*, 36 Monash U. L. Rev. 15 (2010).

53 Landgericht Essen [District Court Essen] Dec. 15, 2016, 2 O 285/15 (Ger.).

54 The provision does not require that the property is located in Germany. Further, even a party that acts lawfully may be held liable for damage caused, a legal principle that underlies Bürgerliches Gesetzbuch [BGB] [Civil Code], § 1004 but also (as noted by the Hamm court) Gesetz zum Schutz vor schädlichen Umwelteinwirkungen durch Luftverunreinigungen, Geräusche, Erschütterungen und ähnliche Vorgänge [BImSchG] [Federal Emission Control Act] § 14(a).

55 *See* Richard Heede, *Tracing Anthropogenic Carbon Dioxide and Methane Emissions to Fossil Fuel and Cement Producers, 1854-2010*, 122 Climatic Change 229 (2013) (presenting a ground-breaking quantitative analysis of the historic fossil fuel and cement production records of fifty leading investor-owned, thirty-one state-owned and nine nation-state producers of oil, natural gas coal, and cement, and finding He that ninety of these 'carbon major' entities are responsible for nearly two-thirds of historic carbon dioxide and methane emissions).

56 *See* Heede, *supra* note 55.

57 In German civil law, equivalent causation is the first step of the test, and the theory of adequate causation functions as a normative corrective The theory of adequate causation is used to eliminate *unlikely* factors from the causal chain; *See also* Palandt, *supra* note 42, at § 249.

58 Oberlandesger Hamm [Regional Court of Hamm] Feb. 1, 2018, Rechtsprechung Der Oberlandesgerichte in Zivilsachen [OLGZ] 15, 17 (Ger).

59 *Id.*

60 The court will only hear evidence if the legal argument is conclusive (Schlüssigkeitsprüfung) so that if the facts can be proven, the legal requirements of the statutory provision are fulfilled. The court stated in the order for hearing evidence that concerns regarding the admissibility and conclusiveness of the claim are not justified on the basis of the current factual and legal situation.

61 *Gray v. The Minister for Planning* [2006] NSWLEC 720 (Austl.).

62 *Id.* at 100.

63 *Urgenda Foundation v The State of the Netherlands* C/09/456689/HA ZA 13-1396 (24 June 2015) ECLI:NL:RBDHA:2015:7196 (unofficial English translation, only the Dutch text of the ruling is authoritative, ECLI:NL:RBDHA:2015: 7145) [4.90]; *The State of the Netherlands v Urgenda Foundation* 200.178. 245/01 (9 Oct. 2018) ECLI:NL: GHDHA:2018:2610 (unofficial English translation) [64].

64 A tutela is a legal remedy to protect fundamental rights. The Supreme Court of Justice ordered the protection of the Colombian Amazon from deforestation through an intergenerational pact for the life. *See* Corte Suprema de Justicia [C.S.J.] [Supreme Court] 5 abril 2018, STC4360-2018 (Colom.).

65 *Gloucester*, *supra* note 8, at 525.

66 *Id.*

67 For the underlying role of these principles for justice consideration *see* John Rawls, Justice as Fairness: A Restatement (Erin I. Kelly ed. 2001). This lack of normative correctives is partly due to the fact that climate change involves a convergence of factors which constantly threaten ethical behaviour and defy moral standards. For a discussion of these moral dimensions, see Stephen M. Gardiner, A Perfect Moral Storm: The Ethical Tragedy of Climate Change (2011); Stephen M. Gardiner & David A. Weisbach, Debating Climate Ethics (2016). Normative correctives could be developed in a similar fashion as in the law of torts, where it is accepted that the person who suffered the harm should be compensated.

68 This is a persistent logical challenge in social sciences, see Max Weber, *Critical Studies in the Logic of the Cultural Sciences*, *in* The Methodology of Social Sciences 113, 169-73 (Edward Shils & Henry Finch eds., 1969).

69 Karsten Haustein et al., *A Real-Time Global Warming Index*, 7 Nature Sci. Rep. 1, 3 (2017).

70 Otto et al., *supra* note 3, at 757.

71 *Heatwave in Northern Europe, Summer 2018*, World Weather Attribution (July 28, 2018), https://www.worldweatherattribution.org/attribution-of-the-2018-heat-in-northern-europe/ (last visited Mar. 20, 2020).

72 Friederike E.L. Otto et al., *The Attribution Question*, 6 Nature Climate Change 813, 814 (2016). *See* Michael E. Mann et al., *Assessing Climate Change Impacts on Extreme Weather Events: The Case for an Alternative (Bayesian) Approach*, 144 Climate Change 131 (2017).

73 *See* A. Hannart et al., *Causal Counterfactual Theory for the Attribution of Weather and Climate Related Events*, 97 Bull. Am. Meteorological Soc'y 99 (2016) (discussing the use of the Baynes' theorem in science*); see* Pearl, *supra* note 4; *see* Perry, *supra* note 4.

74 Otto et al., *supra* note 3, at 757, 758.

75 *See* Sjoukje Philip et al., *Attribution Analysis of the Ethiopian Drought of 2015*, 31 J. Climate 2465 (2018).

76 Pearl, *supra* note 4, at 307.

77 *See* Friederike E.L. Otto et al., *Attribution of Extreme Weather Events in Africa: A Preliminary Exploration of the Science and Policy Implications*, 132 Climatic Change 531 (2015).

78 *See also* Luke J. Harrington & Friederike E.L. Otto, *Adapting Attribution Science to the Climate Extremes of Tomorrow*, 13 Envtl. Res. Letters 123006 (2018).

79 *See also* Harrington & Otto, *supra* note 78.

80 Friederike E.L. Otto et al., *Attributing High-Impact Extreme Events Across Timescales--A Case Study of Four Different Types of Events*, 149 Climatic Change 399, 412 (2018).

81 Climate signals are long-term trends and projections that are linked to climate change. Examples are rising sea levels, increasing extreme precipitation, and warming sea surface temperatures.

82 *See* Luke J. Harrington & Friederike E.L. Otto, *Attributable Damage Liability in a Non-Linear Climate*,153 Climatic Change 15 (2019).

83 We thank Lindene Patton for stressing this point and the fact that with the ability to forecast, there comes a duty to do so.

84 Geert Jan Oldenborgh et al., *Attribution of Extreme Rainfall from Hurricane Harvey, August 2017*, 12 Envtl. Res. Letters 12124009 (2017).

85 The confidence level reflects the evaluation of the validity of a finding. Generally, evidence is most robust when there are multiple, consistent and independent sources of high-quality evidence. A level of *confidence* is expressed using five qualifiers: very low, low, medium, high, and very high. It synthesises the scientific judgment about the validity of findings as determined through evaluation of evidence and agreement. *Likelihood* provides calibrated language for describing quantified uncertainty. It can be used to express a probabilistic estimate of the occurrence of a single event or of an outcome (e.g. a climate parameter, observed trend, or projected change lying in a given range). Likelihood may be based on statistical or modelling analyses, elicitation of expert views, or other quantitative analyses. The range is as follows: Virtually certain: 99-100% probability, Very likely: 90-100% probability, Likely: 66-100% probability, About as likely as not: 33-66% probability, Unlikely: 0-33% probability, Very unlikely: 0-10% probability, Exceptionally unlikely: 0-1% probability. *See* Michael D. Mastrandrea et al., Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, 3 (2010).

86 Friederike E.L. Otto et al., *Anthropogenic Influence on the Drivers of the Western Cape Drought 2015-2017*, 13 Envtl. Res. Letters 1240010 (2018).

87 John L. Mackie, The Cement of the Universe: A Study of Causation 160 (1980); Tony Honoré, Responsibility and Fault 94 (1999).

88 Reflecting the idea that an event is caused by all conditions, see John L. Mackie, *Causes and Conditions, in* Causation 35 (Ernest Sosa & Michael Tooley eds., 1993); Phyllis Illari & Federica Russo, Causality: Philosophical Theory meets Scientific Practice 29 (2014); Mill, *supra* note 24, at 367, 373.

89 Mendelson, *supra* note 11, at 2; Jan Dul, *Necessary Condition Analysis (NCA): Logic and Methodology of "Necessary but Not Sufficient" Causality* 16 Organizational Res. methods 10, 16 (2016); Bear F. Braumoeller & Gary Goertz, *The Methodology of Necessary Conditions*, 44 Am. J. Pol. Sci. 844, 846 (2000).

90 Hart & Honoré, *supra* note 20, at 109; James J. Edelmann, *Unnecessary Causation,* 89 Austl. L.J. 1 (2015).

91 Pearl*, supra* note 4, at 311.

92 E can be defined as the global total or narrower, only including specific emitters, see Paul Griffin, The Carbon Majors Database: CDP Carbon Majors Report 2017 7 (2017); Heede, *supra* note 55, at 234.

93 Ned Hall, *Causation and the Price of Transitivity,* 97 J. Phil. 198, 200 (2000); Claudio Pizzi, *Causality and the Transitivity of Counterfactuals,* 7 O Que Nos Faz Pensar 89, 96 (1993); Pearl, *supra* note 4, at 237; Mendelson, *supra* note 11; Suppes, *supra* note 4, at 215.

94 *See* David Keellings & José J Hernández Ayala, *Extreme Rainfall Associated with Hurricane Maria over Puerto Rico and Its Connections to Climate Variability and Change*, 36 Geophysical Res. Letters, 2964 (2019).

95 *See* Oldenborgh et al., *supra* note 84; *see* Harrington & Otto, *supra* note 78.

96 M.M. Vogel et al.*, Concurrent 2018 Hot Extremes Across Northern Hemisphere Due to Human-Induced Climate Change*, 7 Earth's Future 692, 701 (2019).

97 For the latest figures, see World Meteorological Org., The State of Greenhouse Gas in the Atmosphere Based on Global Observations through 2018 (2019).

98 John Cook et al., *Consensus on Consensus: A Synthesis of Consensus Estimates on Human-Caused Global Warming*, 11 ENVTL. Res. Letters 048002 (2016*); See also* Nat'l Aeronautics and Space Admin.*, Scientific Consensus: Earth's Climate is Warming*, Global Climate Change: Vital Signs of the Planet, https://climate.nasa.gov/scientific-consensus/ (last visited Mar. 22, 2020).

99 Intergovernmental Panel on Climate Change, Climate Change 2014: Synthesis Report 17 (Rajendra K. Pachauri et al. eds., 2015) [hereinafter IPCC 2014].

100 IPCC 2014, *supra* note 99, at 27.

101 *Id.* at 17.

102 Changes in many extreme weather and climate events have been observed since about 1950. It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale 6. It is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. *See* IPCC 2014*, supra* note 99, at 5. *See also* Noah S. Diffenbaugh et al., *Quantifying the Influence of Global Warming on Unprecedented Extreme Climate Events* 114 PNAS 4881 (2017).

103 IPCC 2014, *supra* note 99 at 19; *see* Geert Jan van Oldenborgh et al., *Extreme Heat in India and Anthropogenic Climate Change*, 18 Nat. Hazards & Earth Sys. Sci. 365 (2018); *see* Gabriele C. Hegerl et al., *Causes of Climate Change over the Historical Record,* 14 ENVTL. Res. Letters 123006 (2019).

104 IPCC 2014, *supra* note 99, at 5.

105 *Id.* at 9.

106 Mackie*, supra* note 87, at 35.

107 David Lewis, Philosophical Papers: Volume II 225, 226 (1986).

108 World Meteorological Org., *supra* note 97, at 6.

109 IPCC 2014*, supra* note 99, at 11, 13.

110 *See* Brian C. O'Neill et al., *IPCC Reasons for Concern Regarding Climate Change Risks*, 7 Nature Climate Change 28 (2017).

111 Mackie, *supra* note 88, at 35; Illari & Russo, *supra* note 88, at 29.

112 Mill, *supra* note 24, at 373, 406.

113 Rothman, *supra* note 19, at 590.

114 Wright, *supra* note 5, at 1001.

115 *But see* Richard W. Wright, *The NESS Account for Natural Causation: A Response to Criticism, in* Critical Essays on "Causation and Responsibility" 13, 15 (Benedikt Kahmen & Markus S. Stepanians eds., 2013); Jonathan Schaffer, *Contrastive Causation in the Law*, 16 Legal Theory 259, 287 (2010) (arguing that the NESS test is an excellent test and adding that it is an companion to Schaffer's contrastive approach).

116 Pearl*, supra* note 4, at 308.

117 This means that they only exist in the concrete instance; *see* Mackie, *supra* note 88; *but see* Pearl, *supra* note 4, at 314.

118 Jaegwon Kim, *Causes and Events: Mackie on Causation, in* Causation 60, 62 (Ernest Sosa & Michael Tooley eds., 1993).

119 Pearl, *supra* note 4, at 316.

120 *Id.* at 309.

121 Pearl, *supra* note 4, at 317; Rothman, *supra* note 19, at 587.

122 Pearl, *supra* note 4, at 317.

123 Over an observation period from 1961 to 2016, global glacier mass changes cumulated to -9,625 ± 7,975 Gt (1 Gt = 1012 kg), for specific information and regions (including the Andes), *see* M. Zemp et al., *Global Glacier Mass Changes and Their Contributions to Sea-Level Rise from 1961 to 2016*, 568 Nature 382 (2019).

124 *See* P. Uhe et al., *Comparison of Methods: Attributing the 2014 Record European Temperatures to Human Influences*, 43 Geophysical Res. Letters 8685 (2016). For the predictions of future hydro-meteorological time series in the UK, see Benoit P. Guillod et al., *A Large Set of Potential Past, Present and Future Hydro-Meteorological Time Series for the UK*, 22 Hydrol & Earth Sys. Sci. 611, 629 (2018).

125 *See* IUCN World Commission on Environmental Law, IUCN Declaration on the Environmental Rule of Law (2016); Fisher & Scotford, *supra* note 15.

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